The Impact of Large Optical Surveys on Stellar Astronomy and Variable Star Research

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The 105th Annual Meeting of the AAVSO, Nov 10–12, 2016, Boston

Apache Point Observatory, New Mexico

Who am I?

I became interested in astronomy when I was 10 (in a far away country Yugoslavia, in the part now called Croatia…)

When I was 14 (in 1979!), I started observing variable stars using first the Pickering's method (simple), and then the Argelander's method (0.1 mag precision for by-eye observations!)

At that time, I already knew about the famous AAVSO;
I can't believe I am actually delivering a lecture to you!

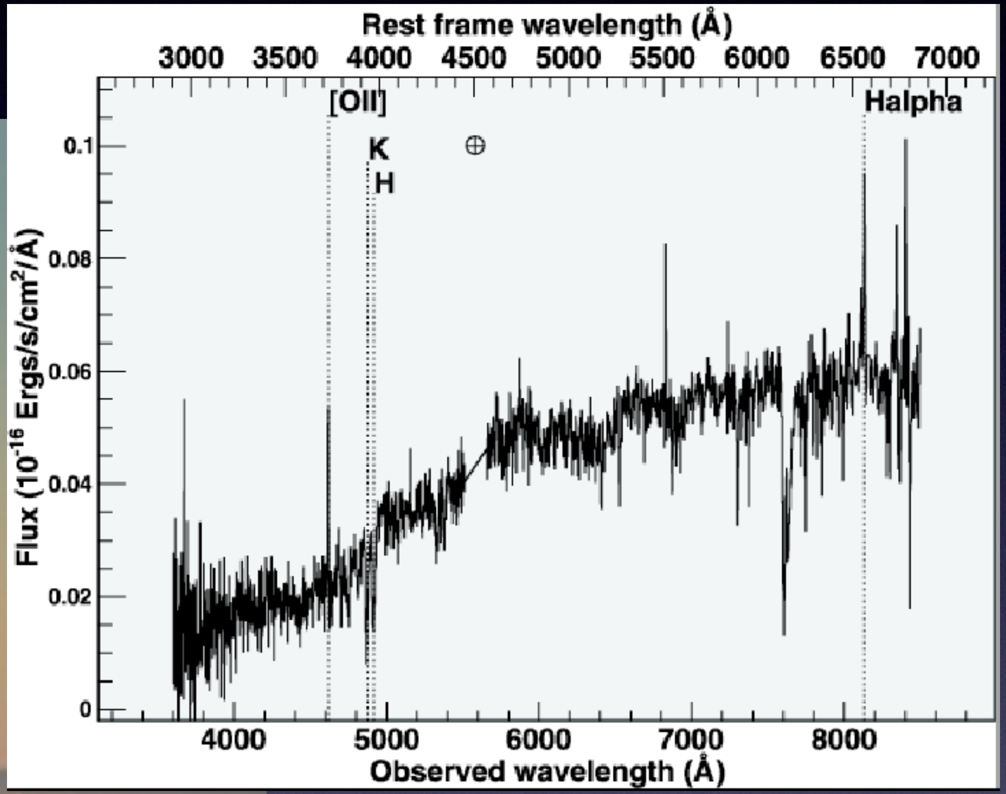
Meanwhile, I decided to turn my hobby into a professional engagement, moved to the U.S., and am now a happy professor of astronomy at the University of Washington.

Topics:

- **Brief introduction to sky surveys:** from Hipparchos to digital sky surveys
- **The first large digital color map of the night sky:** Sloan Digital Sky Survey (SDSS)
- **Astronomy from your armchair:** How to use public SDSS databases? A peek into the soon-to-come future: LSST
- **Commentary:** Are these surveys good for you (AAVSO)?

Context: modern observational methods in astronomy and astrophysics:

- Large telescopes (~10m): faint objects, especially spectroscopy



The Keck telescopes on Mauna Kea (Hawaii)

Context: modern observational methods in astronomy and astrophysics:

- Telescopes above the atmosphere:
  high angular resolution (e.g., the Hubble Space Telescope) and other wavelength regions (X-ray, radio, infrared)

The HST in orbit and an example of a galaxy image

Context: modern observational methods in astronomy and astrophysics:

- **Large telescopes (~10m):** faint objects, especially spectroscopy
- **Telescopes above the atmosphere:** high angular resolution (e.g., the Hubble Space Telescope) and other wavelength regions (X-ray, radio, infrared)
- **Large sky surveys:** digital sensor technology (CCD: charge-coupled device), information technology (data processing and data distribution)

Key point: modern sky surveys make all their data (images and catalogs) publicly available

The era of surveys…

"Ask Not What Data You Need To Do Your Science, Ask What Science You Can Do With Your Data."

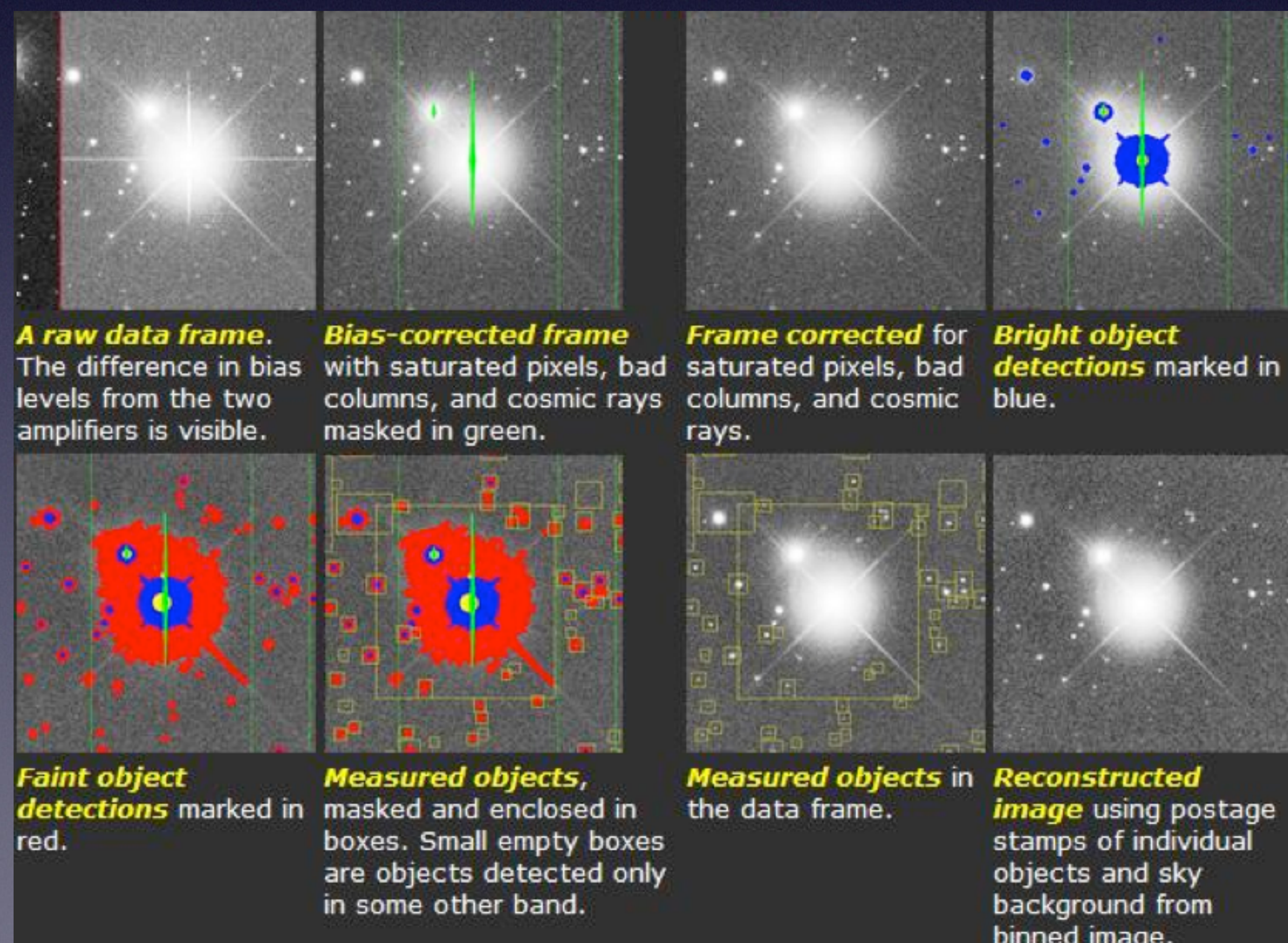
What is a sky map?

Why are sky maps useful?

Meredith Rawls (this morning):
Big Software for Big Data:
Scaling Up Photometry for LSST

- Sky map:
  - a list of all detected objects (stars, galaxies, ...)
  - measured parameters (size, color, brightness,...)

Basic steps in astronomical image processing (example: Sloan Digital Sky Survey):



All these (complicated) steps are already done: "science-ready database"

What is a sky map? Why are sky maps useful?

- Sky map:
  - – a list of all detected objects (stars, galaxies, ...)
  - – measured parameters (size, color, brightness,...)

- The utility of sky maps:

Discoveries of new objects: "Is this a new asteroid, or is it already cataloged?"

Object classification: "What types of galaxies exist?"

Statistical population studies: "Do quasars change their properties with time?"

Search for unusual objects: "Is this star very weird?"

Cosmological measurements: "How fast does the Universe expand?"

Selecting objects for follow-up: e.g. by AAVSO!

"Science-ready database": measurements can be (simply) analyzed without the need for (complex) image processing

An extremely short history of sky mapping

- Hipparchos

  – about 3,000 years ago
  – all stars visible from Greece: about 3,000
  – the main source of astronomical measurements for the next 2,500 years!

- Tycho Brahe

  – XVI century, much more accurate measurements than Hipparchos
  – still without a telescope: about 3,000 stars
  – the main results: Kepler's Laws of planetary motions, Newton's theory of gravity

Modern sky mapping

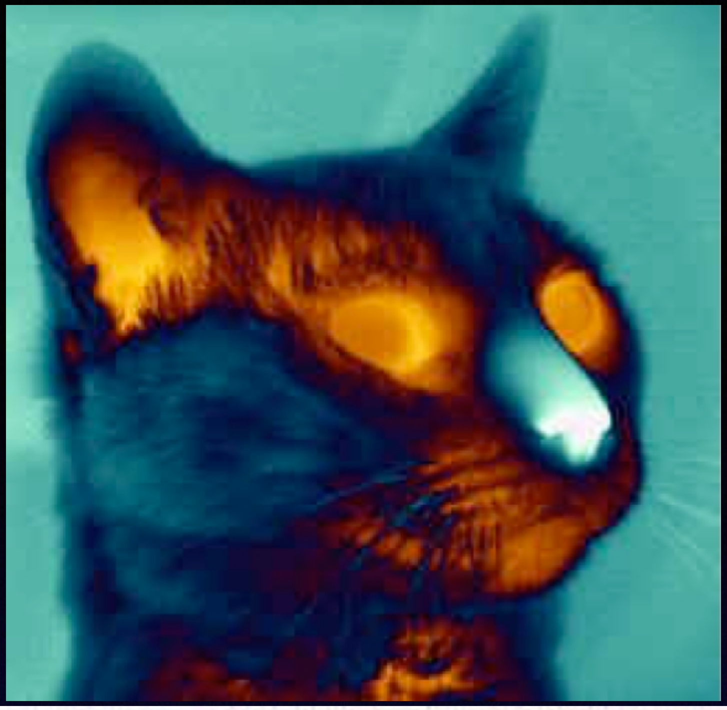
- Palomar Observatory Sky Survey
  (National Geographic Sky Survey):
  – optical wavelengths, two bandpasses
  – 1950-1955 (second phase in 80's)
  – about 1,000 photographs (whole sky)

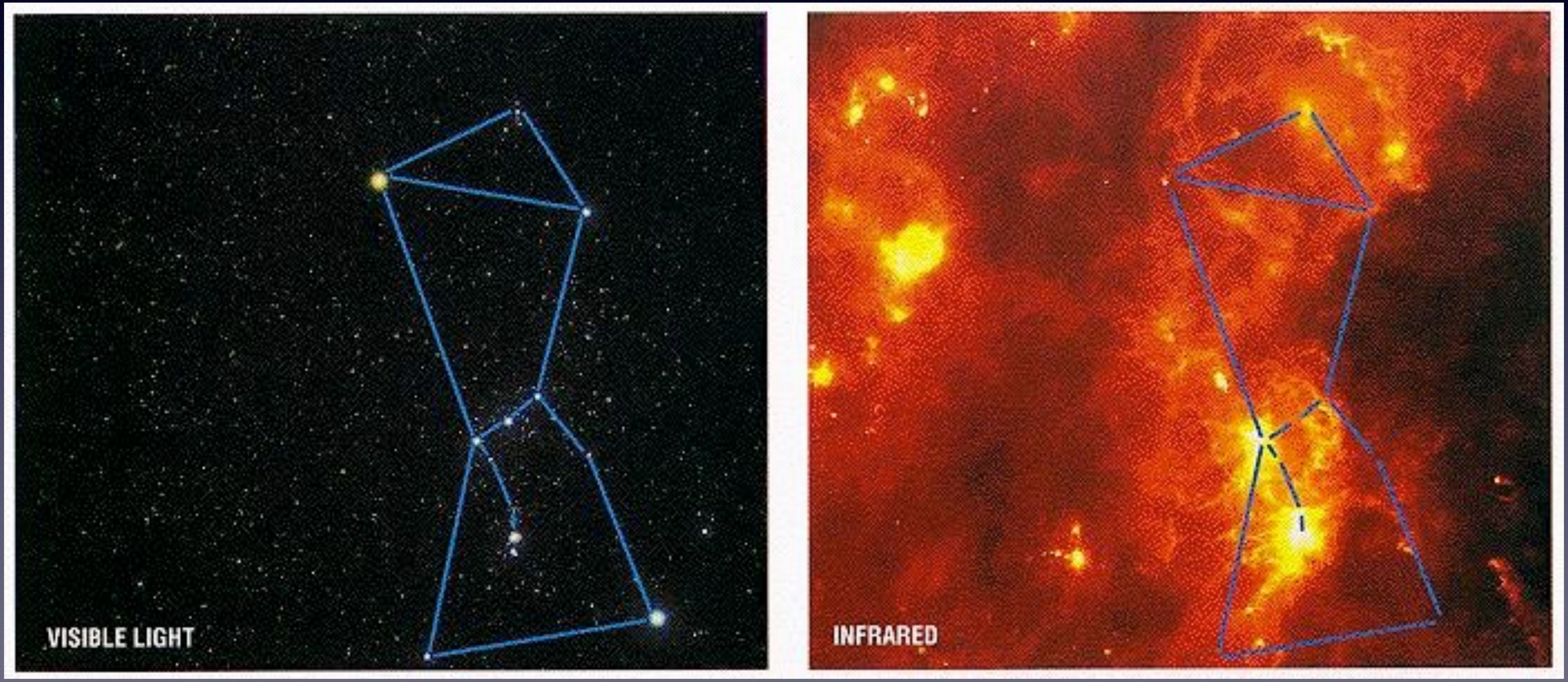
- Other wavelengths:
  – X rays (Chandra, XMM-Newton)
  – ultraviolet (GALEX)
  – infrared (2MASS, Spitzer)
  – radio (FIRST, NVSS)

- Ongoing optical surveys

Optical wavelengths reveal only a bit of reality…

Space-based surveys are uniquely important!





Orion: visible light infrared light

Modern sky mapping

- Ongoing/upcoming optical (visual) surveys:
  - Sloan Digital Sky Survey
  - LINEAR Survey
  - Catalina Sky Survey
  - Palomar Transient Factory
  - Pan-STARRS
  - Dark Energy Survey
  - Gaia (space based)
  - Zwicky Transient Facility
  - Large Synoptic Survey Telescope

Modern sky mapping

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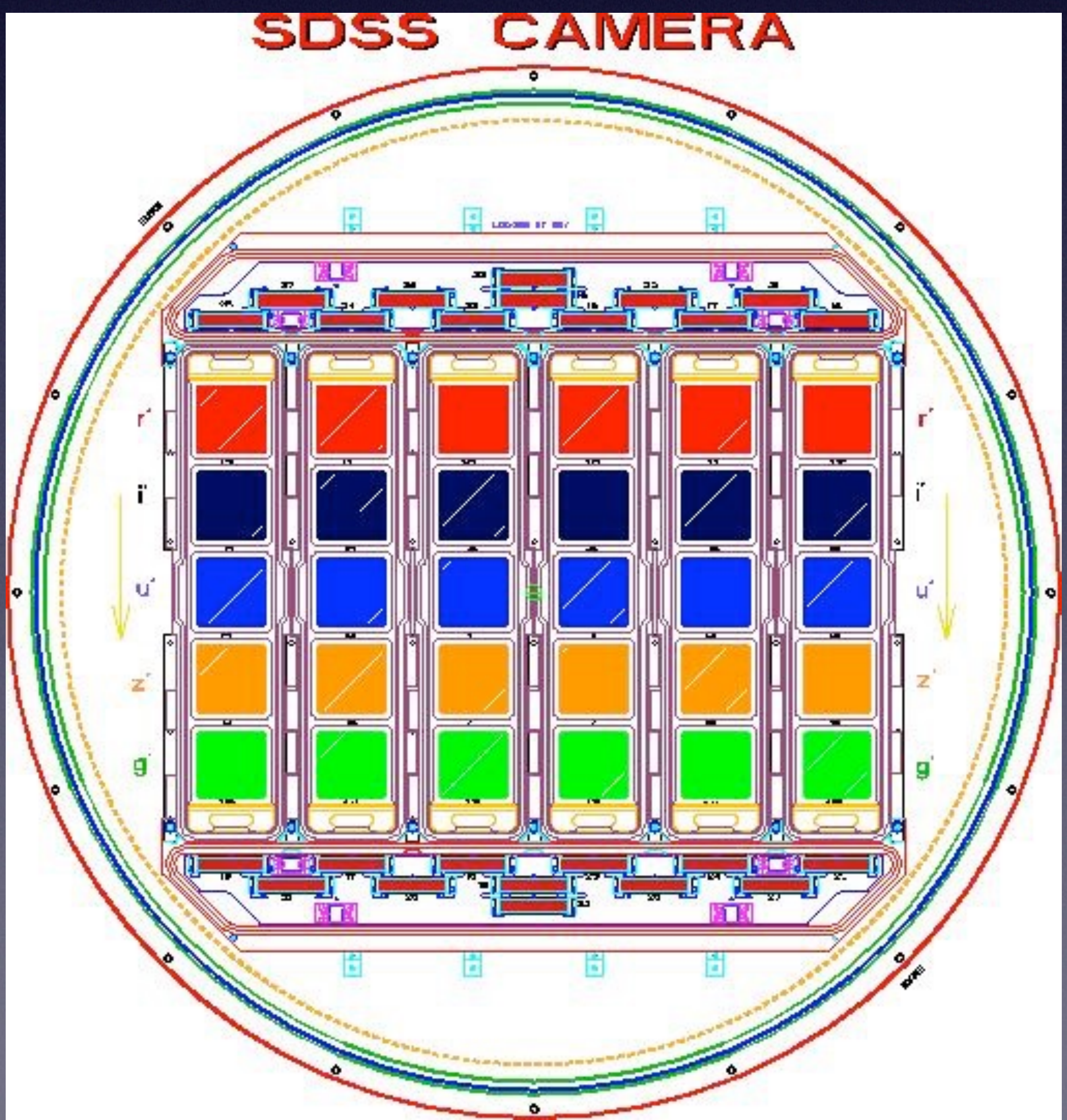
This rapid progress is transforming the field of variable stars - is there anything left for AAVSO to do?

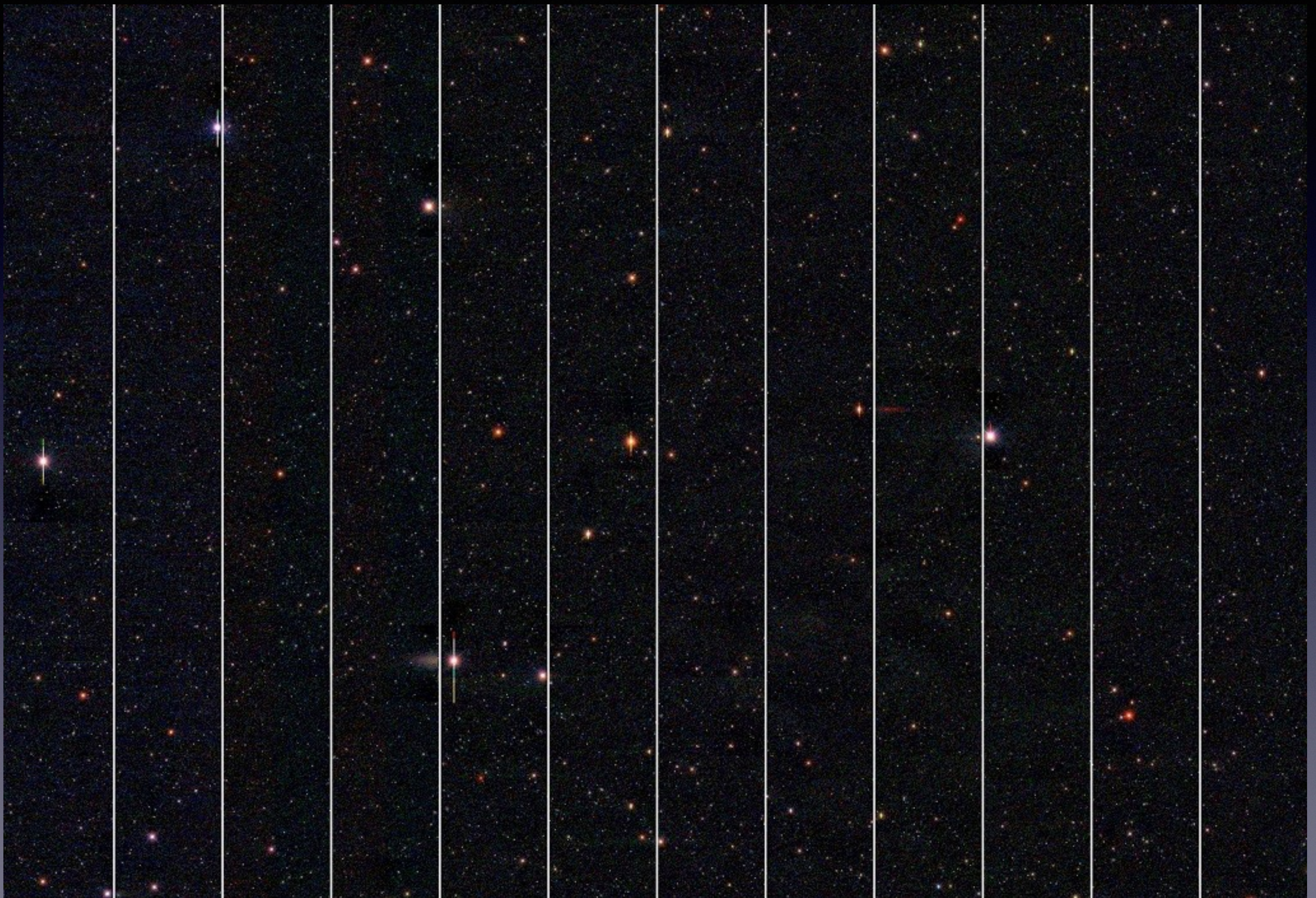
Sloan Digital Sky Survey:
the first massive digital color map of the night sky

Started in 1998: the Sloan Digital Sky Survey

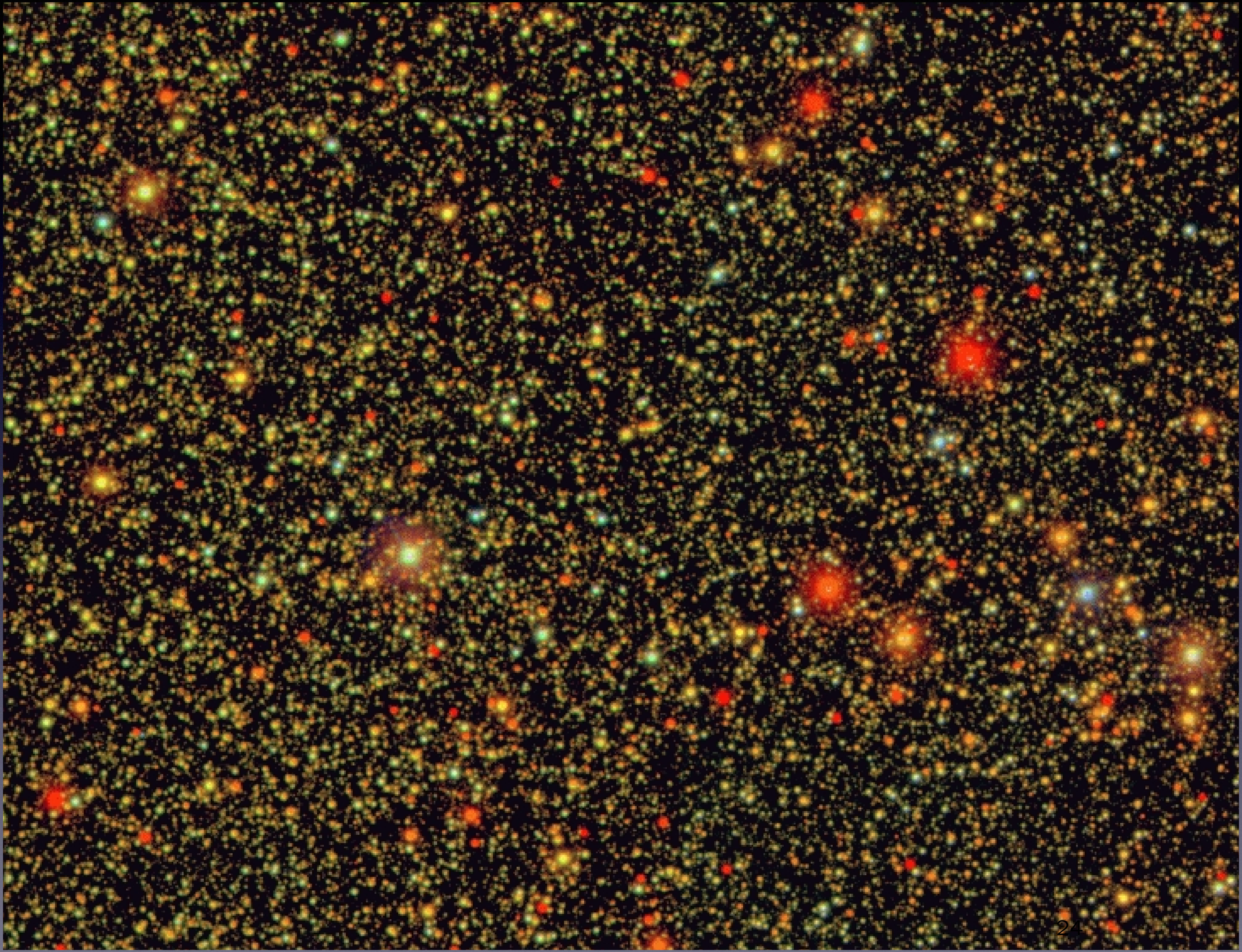
- Digital sky survey with a 120 Megapix CCD camera
- Precise measurements for 400,000,000 objects
- Revolution in astronomy: public databases



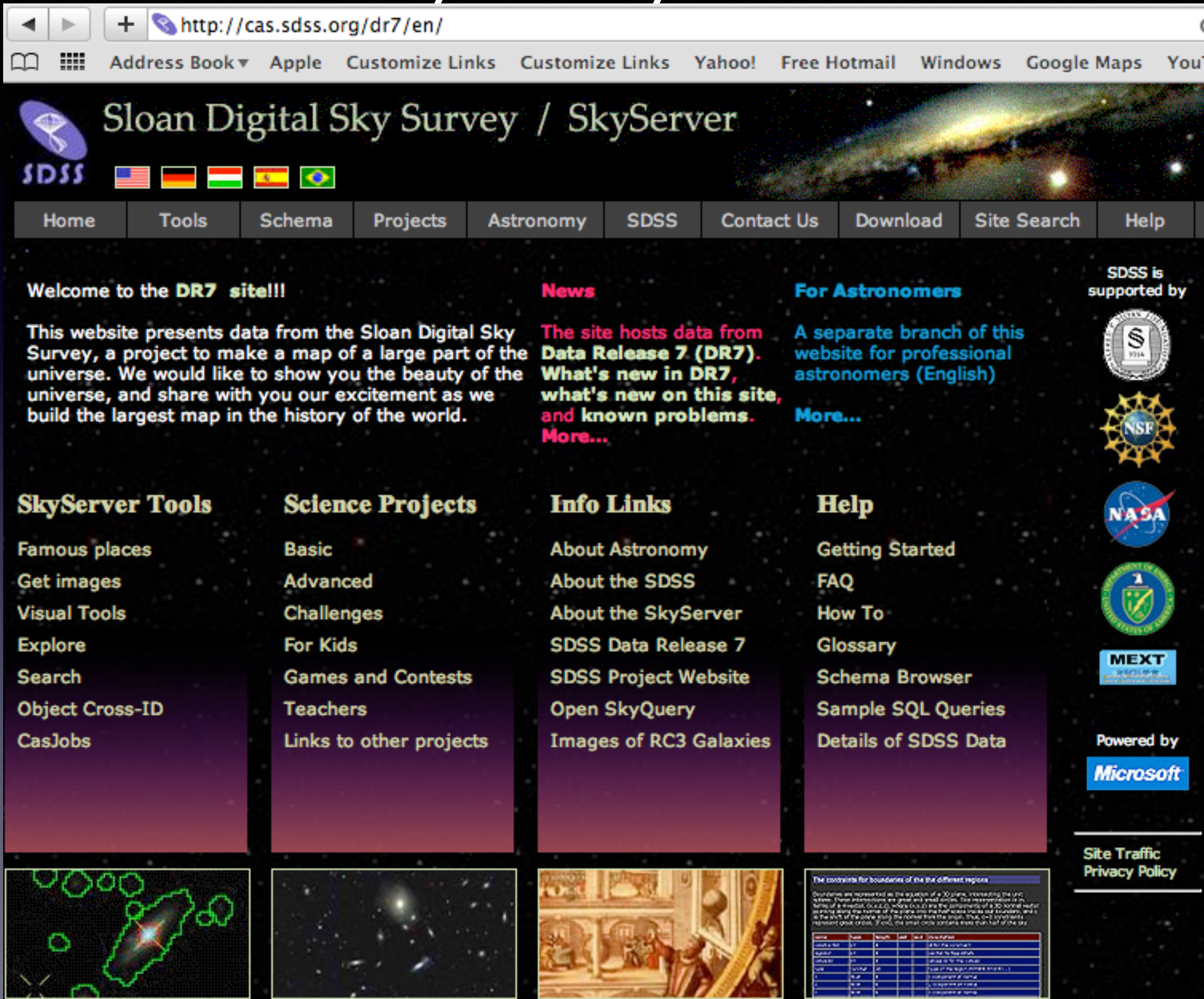
SDSS sky mapping: "drift scanning"



SDSS view along the Milky Way Disk



Astronomy "from your armchair"



Lessons are available on a wide variety of topics including:

- The Hubble Diagram
- Colors in Astronomy
- Spectral Types of Stars
- Image Processing
- Asteroids
- The H-R Diagram
- Galaxies
- Sky Surveys
- Quasars

More lesson plans are being added on a regular basis, so check back soon!

What materials are available for teachers?

Teacher's pages are available for all lessons. The teacher's pages include:

- Notes and teaching tips on all lessons
- Sample solutions and scoring rubrics for all questions and exercises
- Strategies to help you fit the lessons into your available time
- Correlations to national Math and Science Standards

How much does this cost?

Nothing!

All materials on SkyServer are available free of charge, including all lesson plans, access to the teacher's pages, and access to all data.

So, how do I access all this material?

All the student lessons can be accessed from the **Projects** main page. All the teacher's pages can be accessed from the **teacher's site**.

To view sample solutions or to use our evaluation forms, please fill out a simple **registration form** (opens in a new window). We will not give your information to any other organization. For details, see our privacy policy.

DR7 Projects

Basic
Advanced
Research Challenges
For Kids
User Activities
Games and Contests
Links to Others

Projects

In our SkyServer Projects, you will learn science by studying the 14 million stars and galaxies of the Sloan Digital Sky Survey (SDSS) - the same objects that professional astronomers study. Most of these objects have never been seen before by human eyes.

STUDENTS:

- **Register** as a SkyServer student user
- **Request answers** to SkyServer projects
- **View answers** you have requested
- **Evaluate** a project you have finished

TEACHERS:

- **Learn** how you can use SkyServer in your classroom
- **See the teacher guides** for SkyServer projects
- **Register** as a SkyServer teacher
- **Communicate** with other teachers on the **SkyServer Yahoo group** (links open in new window)

Work through these projects at your own pace. Each consists of several questions and exercises. If you get stuck, try reading our **About Astronomy** or **About SDSS** pages. The projects include downloadable Excel spreadsheets to help you keep track of your data.

Each project ends with a Research Challenge, which lets you do real astronomy research, just like thousands of professional astronomers around the world. When you finish the Research Challenge for each project, E-mail it to us. We'll look over all the results we get, and we'll put the best up on these pages!

Click on one of the following project categories to get started:

Basic projects	For middle school, high school, and Astronomy 101 students, and for people who want a basic understanding of astronomy

http://cas.sdss.org/dr7/en/proj/default.asp

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Basic projects	For middle school, high school, and Astronomy 101 students, and for people who want a basic understanding of astronomy
Advanced projects	Appropriate for advanced high school and college students, and for people who want a detailed understanding of astronomy
Research Challenges	Independent research in astronomy - you pick a problem and choose how to solve it! The Research Challenges are great for Science Fair projects or guided inquiry activities.
For Kids	Projects designed for kids
Games and Contests	Games for fun, and contests with prizes
Links	A few of the best astronomy education sites on the Internet

Want to hear when we add new projects? Join the **SkyServer mailing list**!

Projects for different ages and levels of background knowledge http://cas.sdss.org/dr7/en/proj/basic/scavenger/objecttypes2.asp

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DR7 Projects

Basic
- Solar System
- Scavenger Hunt
- The Universe
- Asteroids
- Types of Stars
- Color
- Galaxies

Advanced
Research Challenges
For Kids
User Activities
Games and Contests
Links to Others

Scavenger Hunt

Colors
Spectra
Object Explorer
Types of Objects
More Types of Objects
- Asteroids

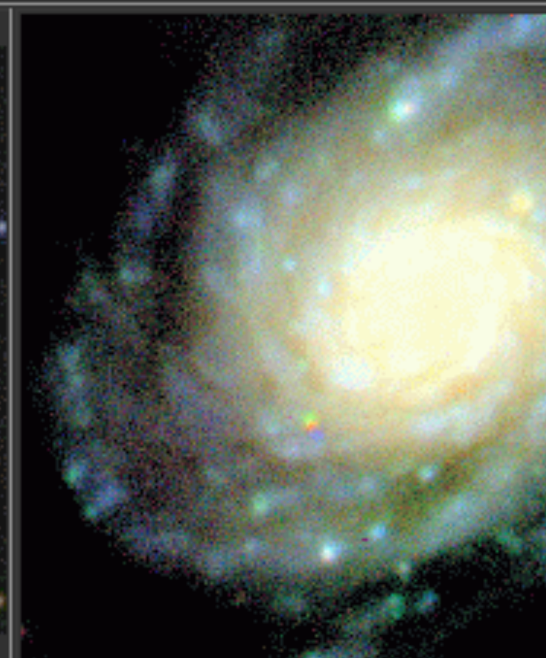
Types of Objects

... from simple to...

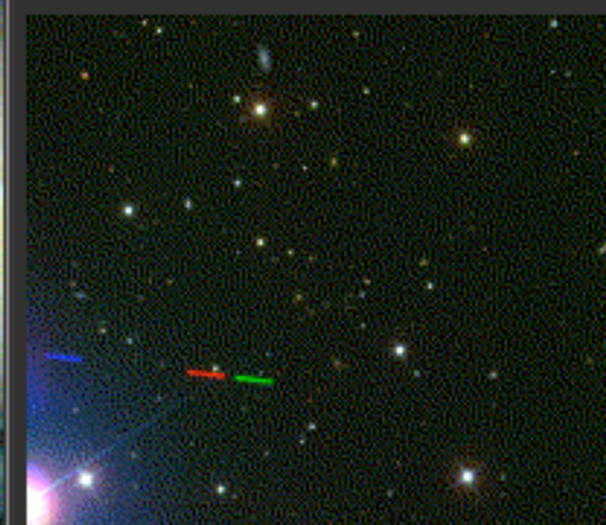
Asteroids

Asteroids are small pieces of rock that orbit the Sun, mostly between Mars and Jupiter. Asteroids move quickly across the sky, so they can be seen in SDSS images (see the **Asteroids** project to learn more). If an asteroid moves slowly, it will show up in images as a blue dot next to a yellow dot. Fast moving asteroids show up as a red, green and blue dot in succession. Very fast moving asteroids may appear as colored streaks. Examples of each type are shown below. Asteroids that appear as blue-yellow dots trick the computer program that classifies objects, so their types are listed as stars.

A slow-moving asteroid



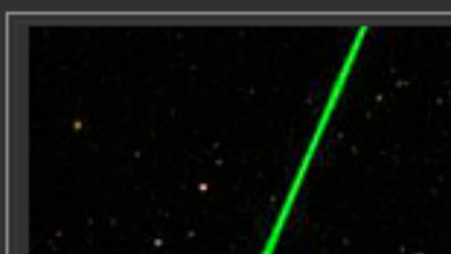
A slightly faster asteroid in front of a galaxy



A very fast-moving asteroid

Meteors

Sometimes, tiny particles of rock or dust fall toward the Earth. As they enter the Earth's atmosphere, they heat up and start to glow. From the ground, we see a long, glowing trail of light that passes quickly through the sky. These trails of light are called ***meteors***. They are also known as shooting stars.



http://cas.sdss.org/dr7/en/tools/search/sql.asp

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... *advanced*

DR7 Tools

- Getting Started
- Famous places
- Get images
- Scrolling sky
- Visual Tools
- Search
  - Radial
  - Rectangular
  - Search Form
  - Query Builder
  - SQL
- Object Crossid
- CasJobs

SQL Search

This page allows you to directly submit a SQL (Structured Query Language) query to the SDSS database server. You can modify the default query as you wish, or cut and paste a query from the SDSS Sample Queries page.

Please note: To be fair to other users, queries run from SkyServer search tools are restricted in how long they can run and how much output they return, by **timeouts** and **row limits**. Please see the Query Limits help page. To run a query that is not restricted by a timeout or number of rows returned, please use the CasJobs batch query service.

Clear Query

```
-- This query does a table JOIN between the imaging (PhotoObj) and spectra
-- (SpecObj) tables and includes the necessary columns in the SELECT to upload
-- the results to the DAS (Data Archive Server) for FITS file retrieval.
SELECT TOP 10
   p.objid,p.ra,p.dec,p.u,p.g,p.r,p.i,p.z,
   p.run, p.rerun, p.camcol, p.field,
   s.specobjid, s.specClass, s.z,
   s.plate, s.mjd, s.fiberid
FROM PhotoObj AS p
   JOIN SpecObj AS s ON s.bestobjid = p.objid
WHERE
   p.u BETWEEN 0 AND 19.6
   AND g BETWEEN 0 AND 20
```

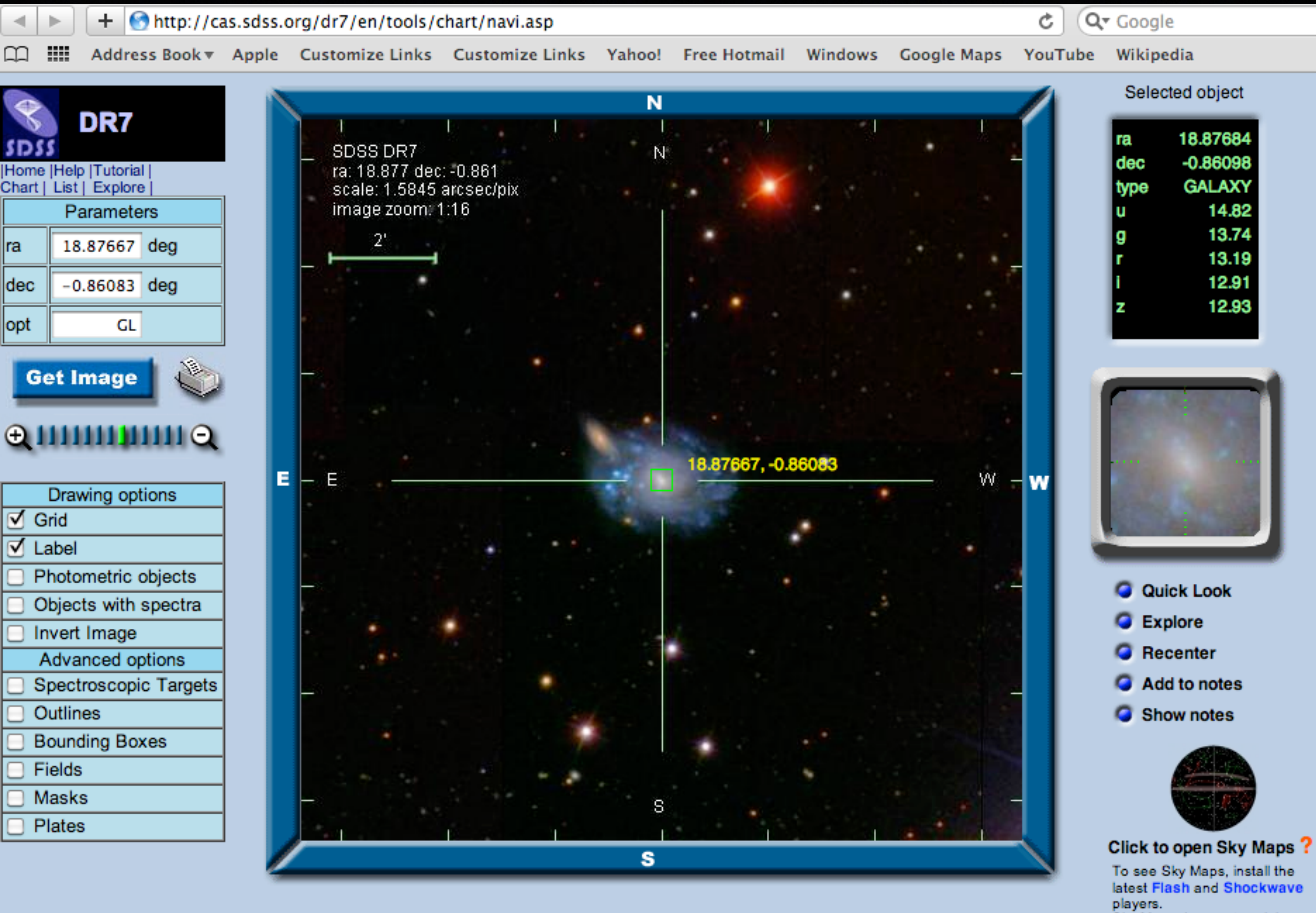
Submit | ☐ Check Syntax Only? | **Output Format** ◉ HTML ○ XML ○ CSV | Reset

To find out more about the database schema use the Schema Browser.

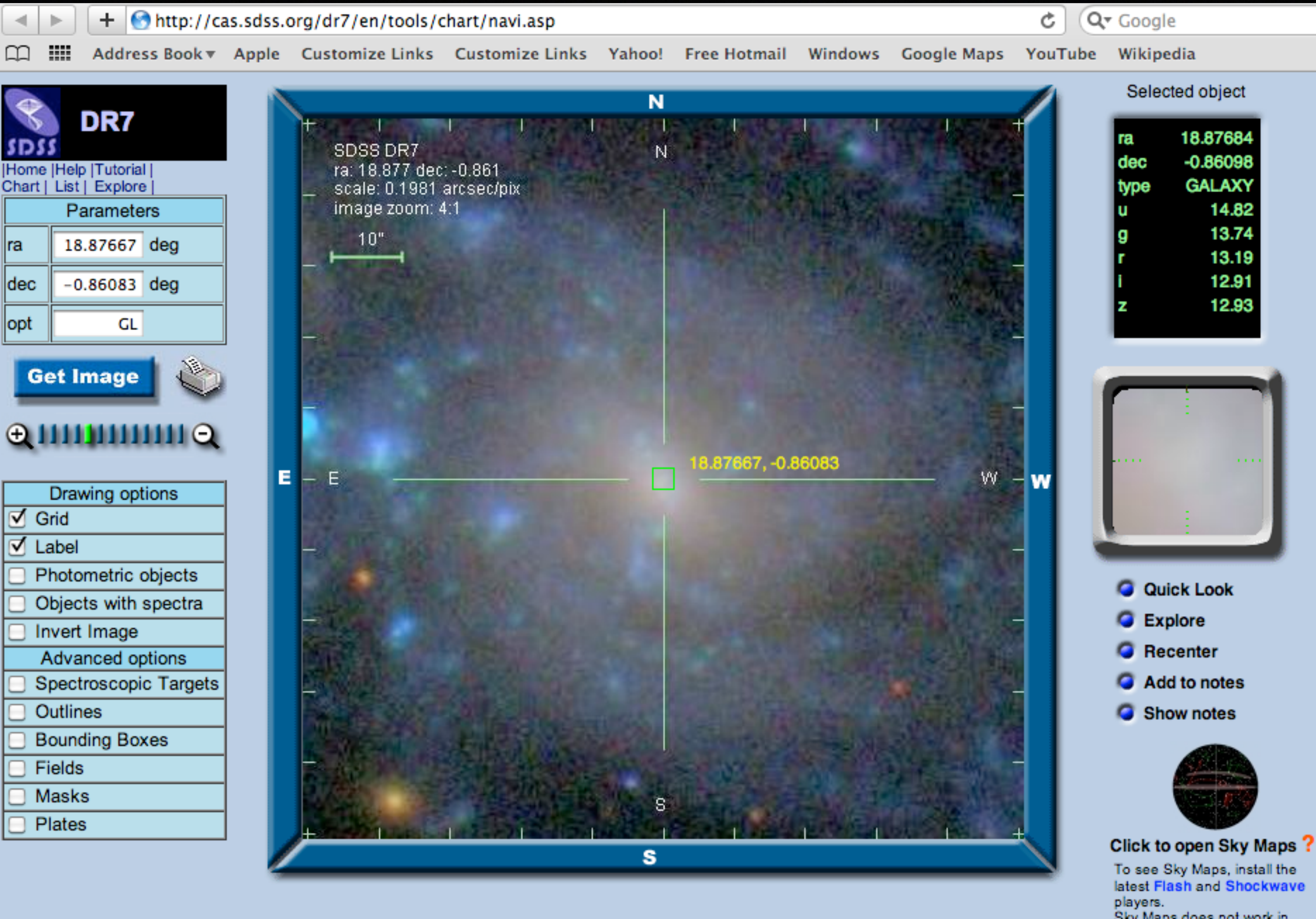
For an introduction to the Structured Query Language (SQL), please see the Searching for Data How-To tutorial. In particular, please read the Optimizing Queries section.

The inclusion of the imaging and spectro columns for DAS upload in your query (as in the default query on this page) will ensure that when you press **Submit**, the appropriate button(s) are displayed on the query results page to allow you to upload the necessary information to the DAS to retrieve the FITS file data corresponding to your CAS query. The imaging columns needed for upload to the DAS are *run*, *rerun*, *camcol*, and *field*. The spectroscopic columns needed are *plate*, *mjd*, *fiberid*, and optionally *sprerun* (the latter requires a join with the PlateX table).

“Navigation” around the sky...



“Navigation” around the sky: zoom in, zoom out...



Additional, more detailed, information...

http://cas.sdss.org/dr7/en/tools/explore/obj.asp?ra=18.87667&dec=-0.86083

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DR7 SDSS

Explore Home

Search by
ObjId
Ra,dec
5-part SDSS
Plate-MJD-Fiber
SpecObjId

Summary

PhotoObj
PhotoTag
More Observations
Field
Frame
PhotoZ
Neighbors
Finding chart
Navigate
FITS

SpecObj
All Spectra
SpecLine
SpecLineIndex
XCredShift
ELredShift
Spectrum
Plate
FITS

NED search
SIMBAD search
AKARI FIS
AKARI IRC
ADS search

Notes
Save in Notes
Show Notes

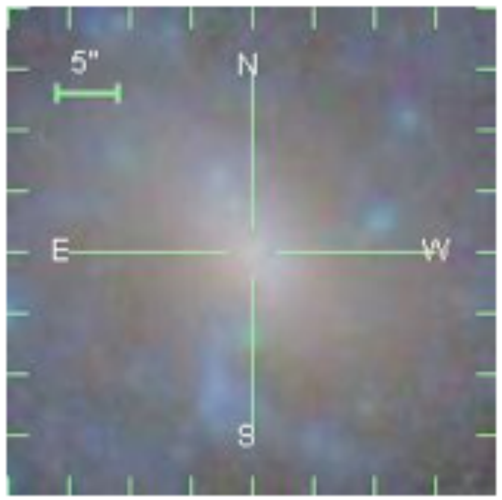
Print

SDSS J011530.44-005139.5

GALAXY ra=18.87683906, dec=-0.86097998, ObjId = 587731511532060697

Column names link to glossary entries. Move mouse over a column name to get its units.

mode	PRIMARY
status	TARGET PRIMARY OK_STRIPE OK_SCANLINE PSEGMENT RESOLVED OK_RUN GOOD SET
flags	DEBLEND_DEGENERATE BAD_MOVING_FIT BINNED1 INTERP COSMIC_RAY NOPETRO CHILD
PrimTarget	TARGET_GALAXY TARGET_GALAXY_RED TARGET_QSO_CAP
SecTarget	



u	g	r	i	z
14.82	13.74	13.19	12.91	12.93

err_u	err_g	err_r	err_i	err_z
0.01	0.00	0.00	0.00	0.00

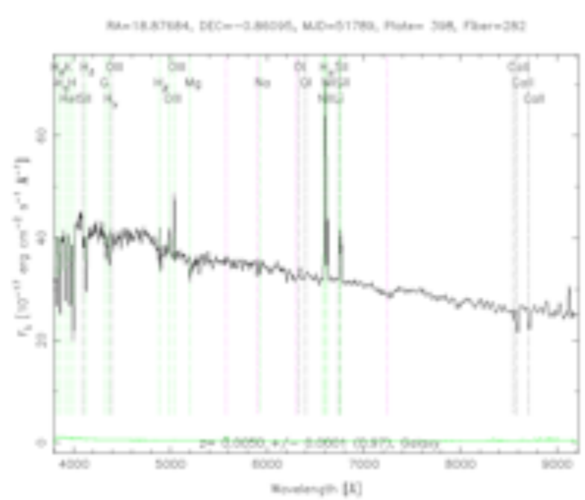
run	rerun	camcol	field	obj	rowc	colc
2738	40	1	44	25	972.5	1786.6

fiberMag_r	petroMag_r	devMag_r	expMag_r	psfMag_r	modelMag_r
17.56	12.97	13.14	13.19	18.16	13.19

extinction_r	petroRad_r	parentId	nChild
0.11	106.724	587731511532060693	0

SpecObjID = 112249473974927360

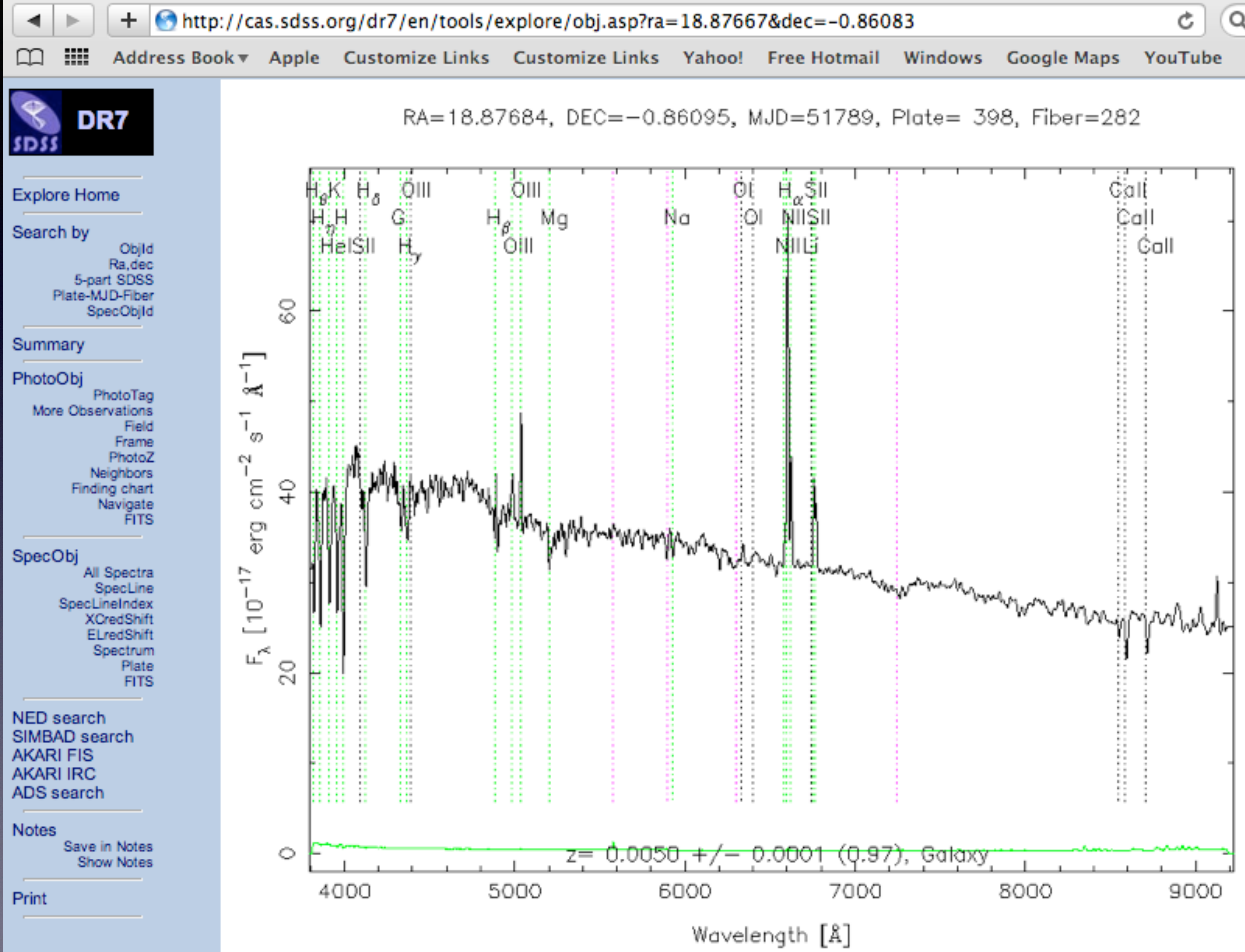
plate	mjd	fiberId	z	zErr	zConf	specClass	ra	dec	fiberMag_r	objId
398	51789	282	0.005	0.00006	0.969081	GALAXY	18.87684	-0.86095	17.53	587731511532060697



zStatus	XCORR_EMLINE
zWarning	OK
PrimTarget	TARGET_GALAXY TARGET_GALAXY_RED
SecTarget	
eClass	0.095797
emZ	0.006
emConf	0.874995
xcZ	0.005
xcConf	0.969081

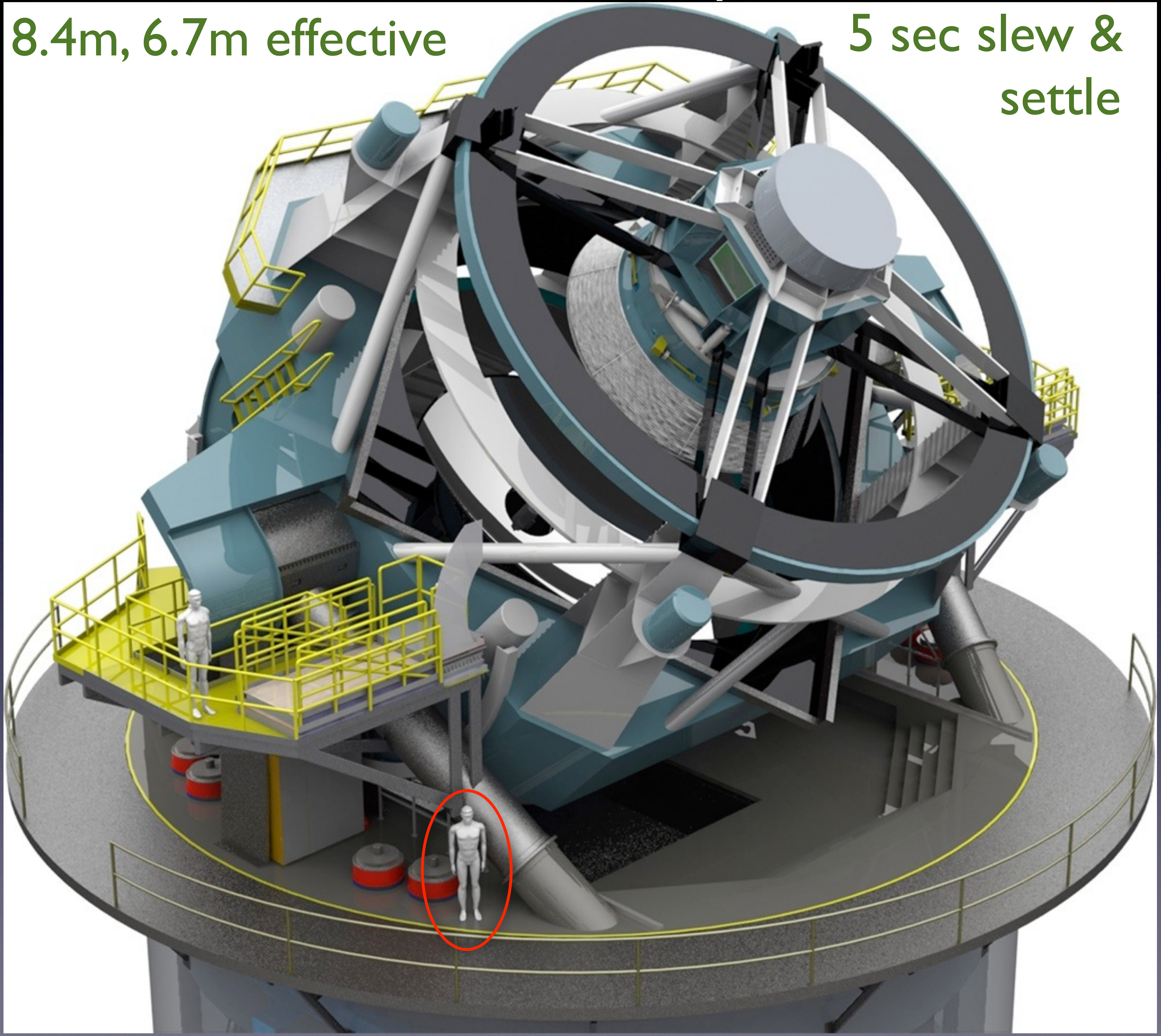
Cross-identifications

For example, spectra (here: a Seyfert [active] galaxy)

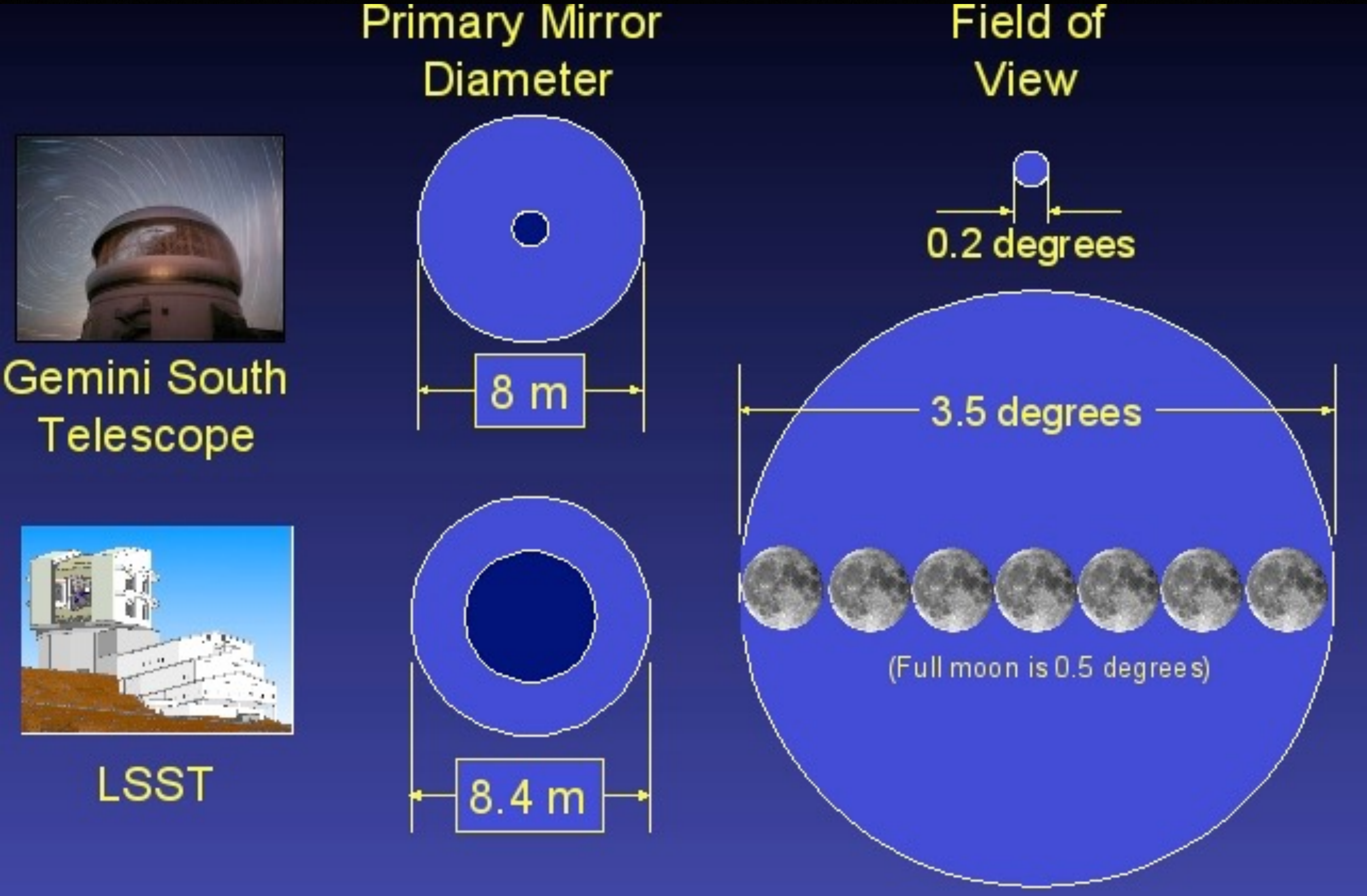


A peek into the future: the Large Synoptic Survey Telescope

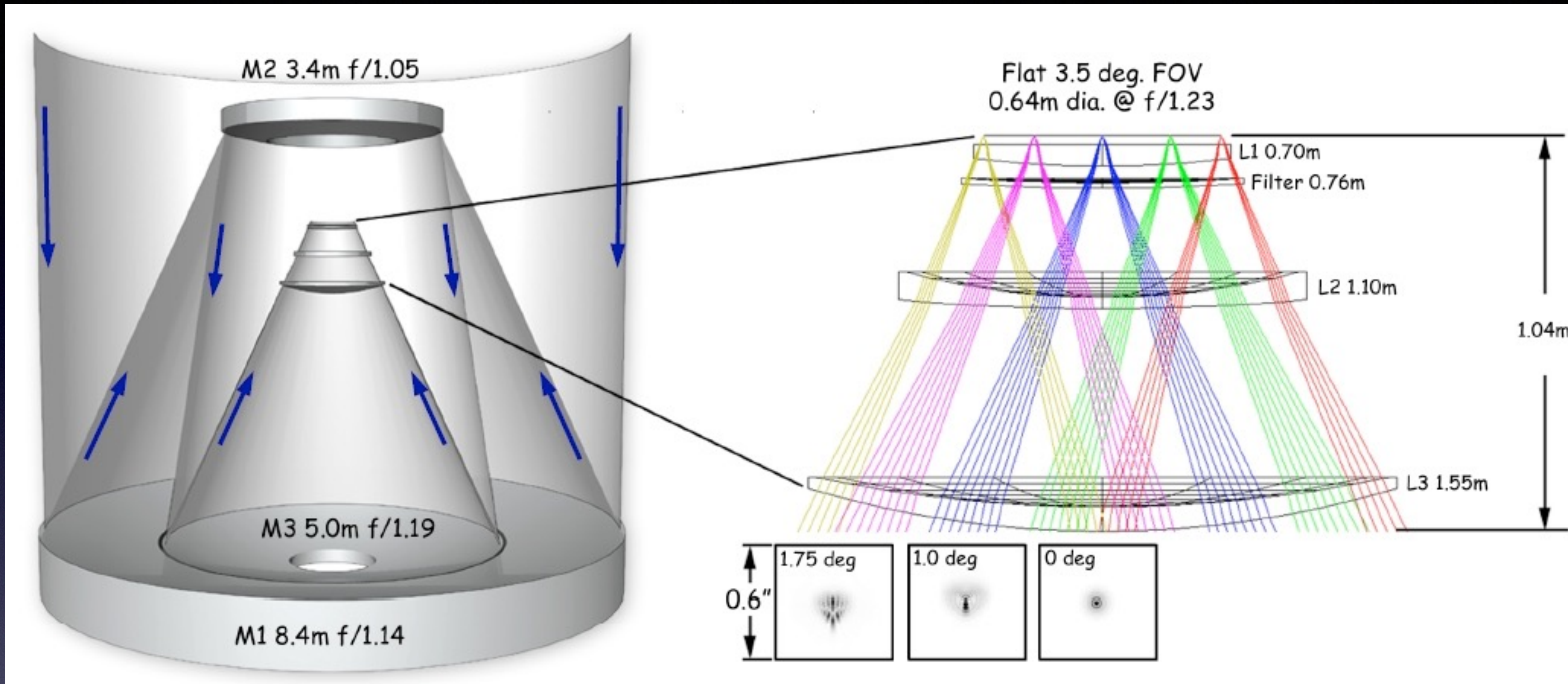
LSST Telescope



Gemini vs. LSST field-of-view comparison



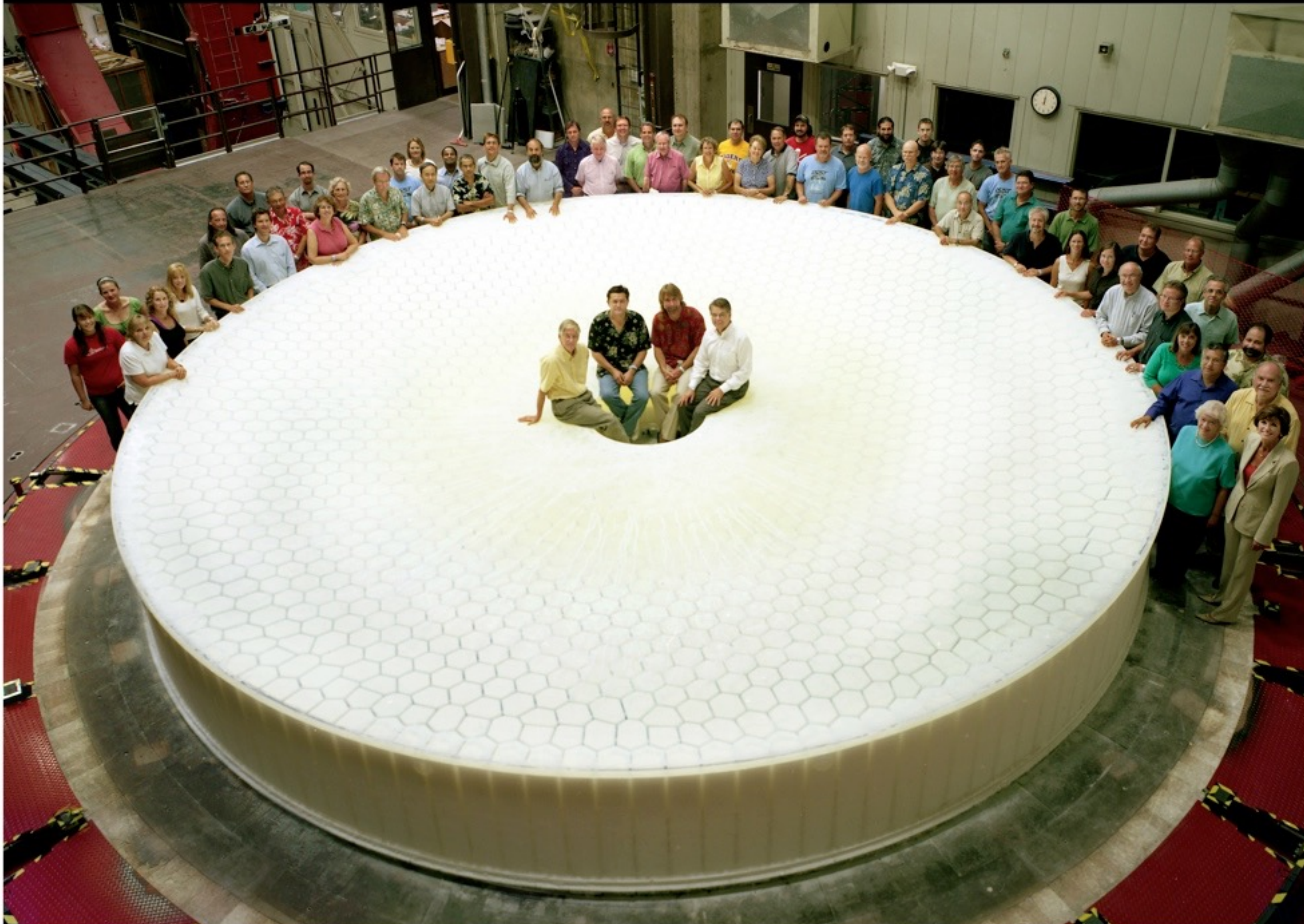
Optical design for the LSST telescope



"Classical" telescopes: two mirrors, hard to simultaneously get both a large field of view **and** small image distortions

LSST: three-mirror design that enables a large field of view with small image distortions (Paul-Baker system)

LSST Large Synoptic Survey Telescope



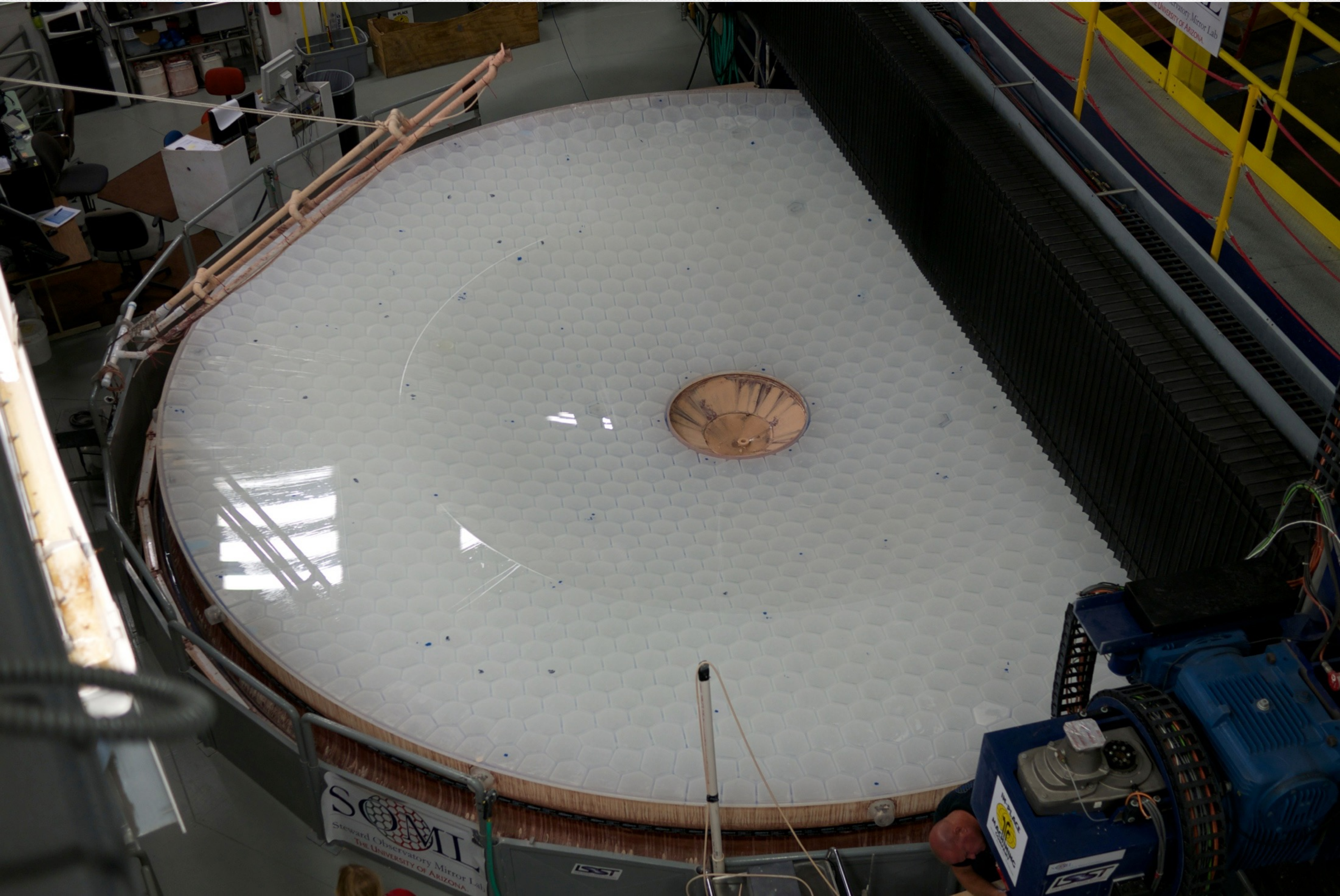
The University of Arizona
Tucson Arizona

SOML

LSST Primary/Tertiary Mirror Blank
August 11, 2008, Steward Observatory Mirror Lab, Tucson, Arizona

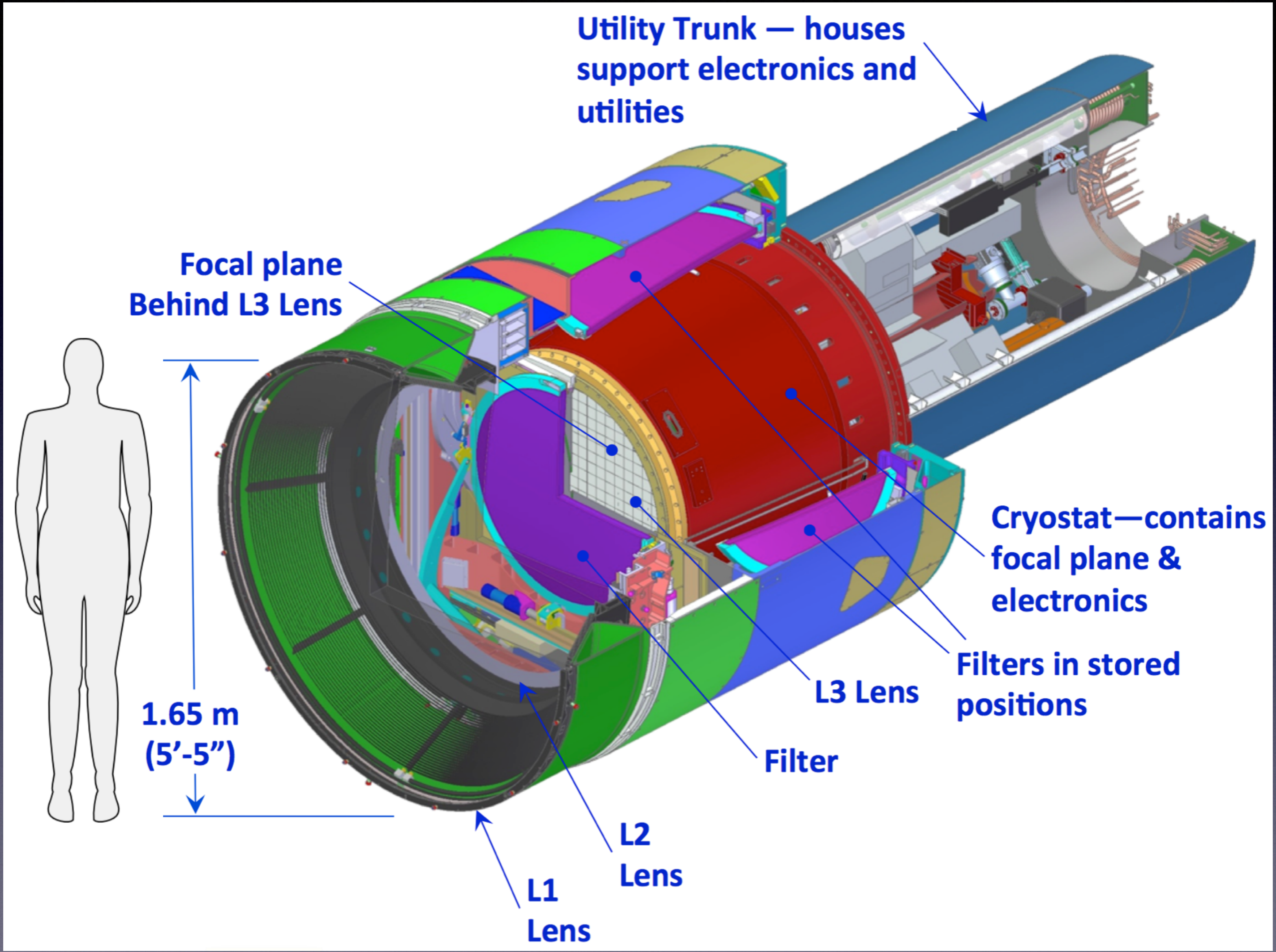
LSST
Large Synoptic Survey Telescope

Done!



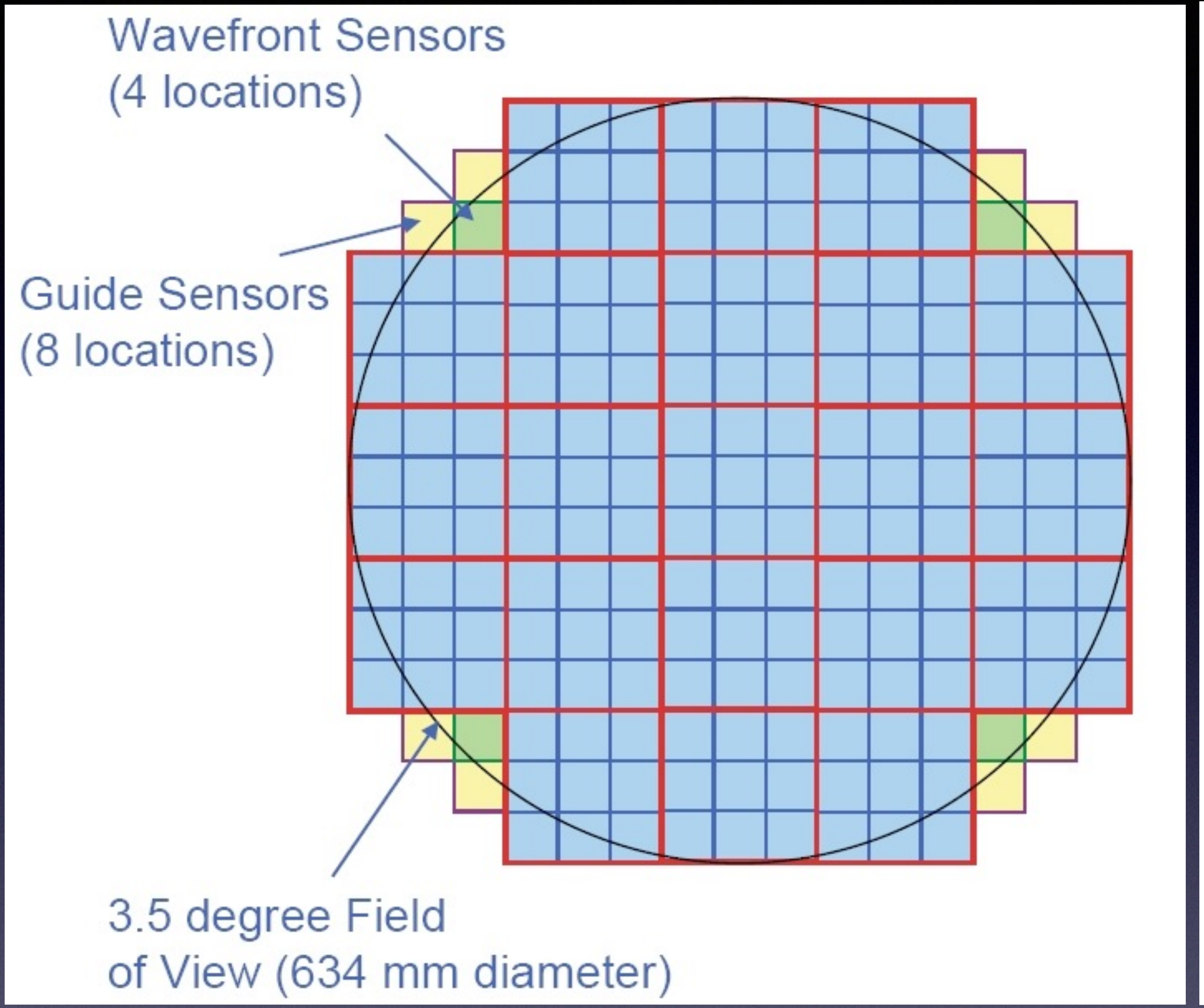
Steward Observatory Mirror Lab
THE UNIVERSITY OF ARIZONA
LSST

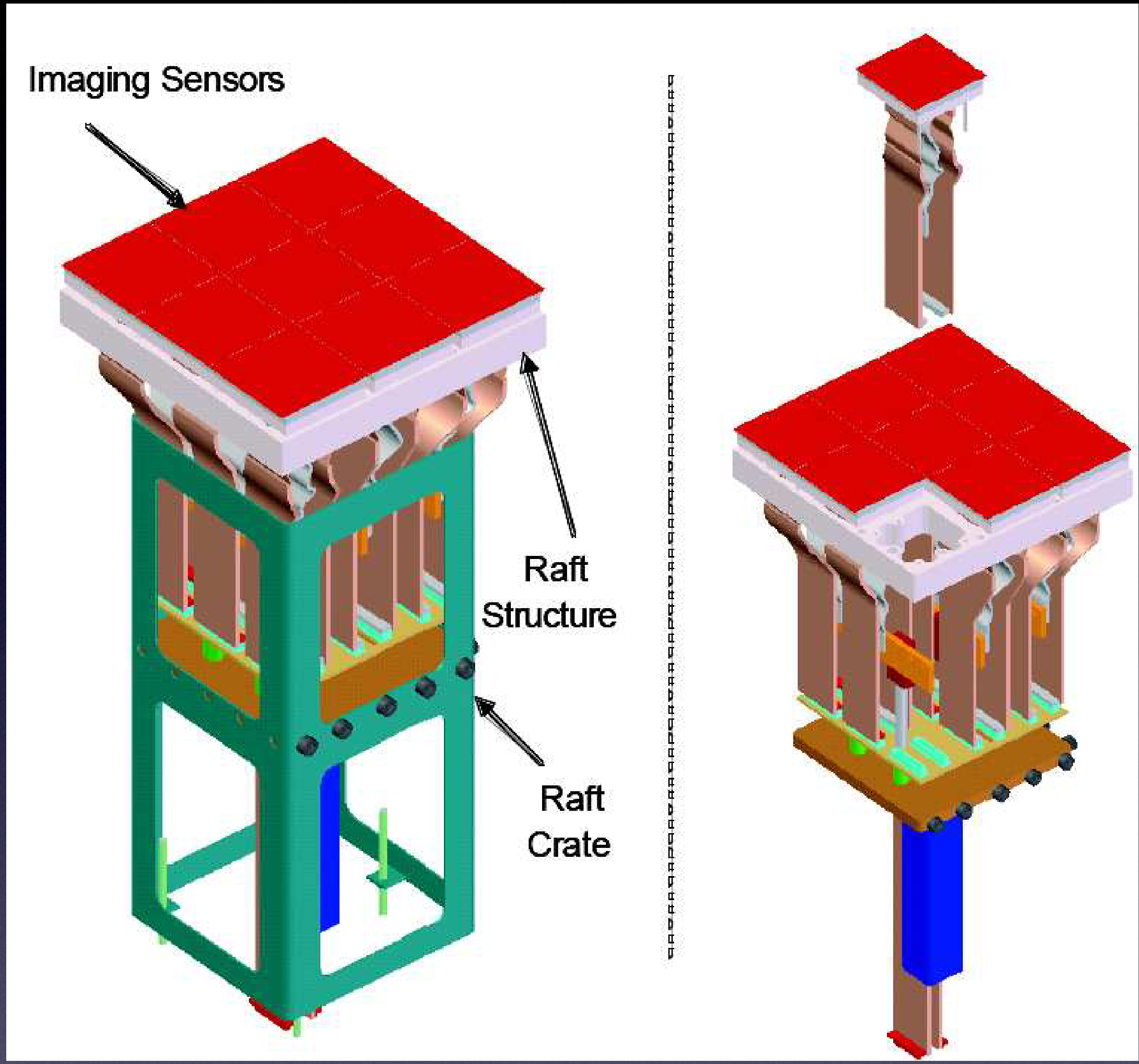
LSST camera



The largest astronomical camera: 2800 kg, 3.2 Gpix

LSST camera





Modular design: 3200 Megapix = 189 x16 Megapix CCD
9 CCDs share electronics: raft (=camera)
Problematic rafts can be replaced relatively easily

SDSS vs. LSST comparison: LSST=d(SDSS)/dt, LSST=SuperSDSS

3x3 arcmin, gri

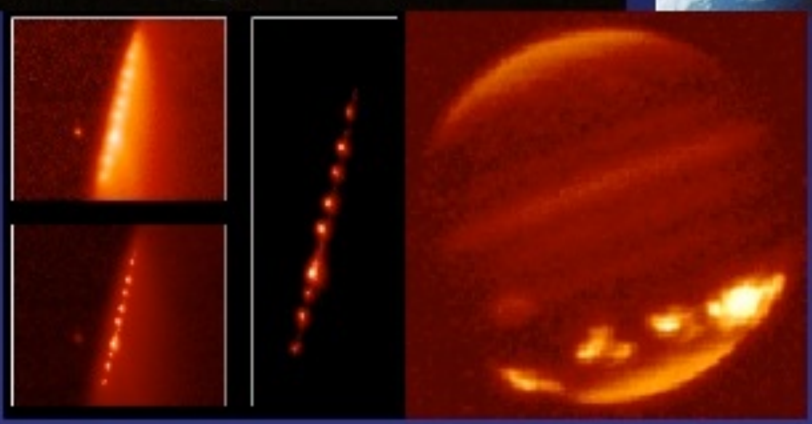
3 arcmin is 1/10 of the full Moon's diameter

(almost) like LSST depth (but tiny area)

20x20 arcsec; lensed SDSS quasar (SDSS J1332+0347, Morokuma et al. 2007)

Killer asteroids: the impact probability is not 0!

LSST is the only survey capable of delivering completeness specified in the 2005 USA Congressional NEO mandate to NASA (to find 90% NEOs larger than 140m)

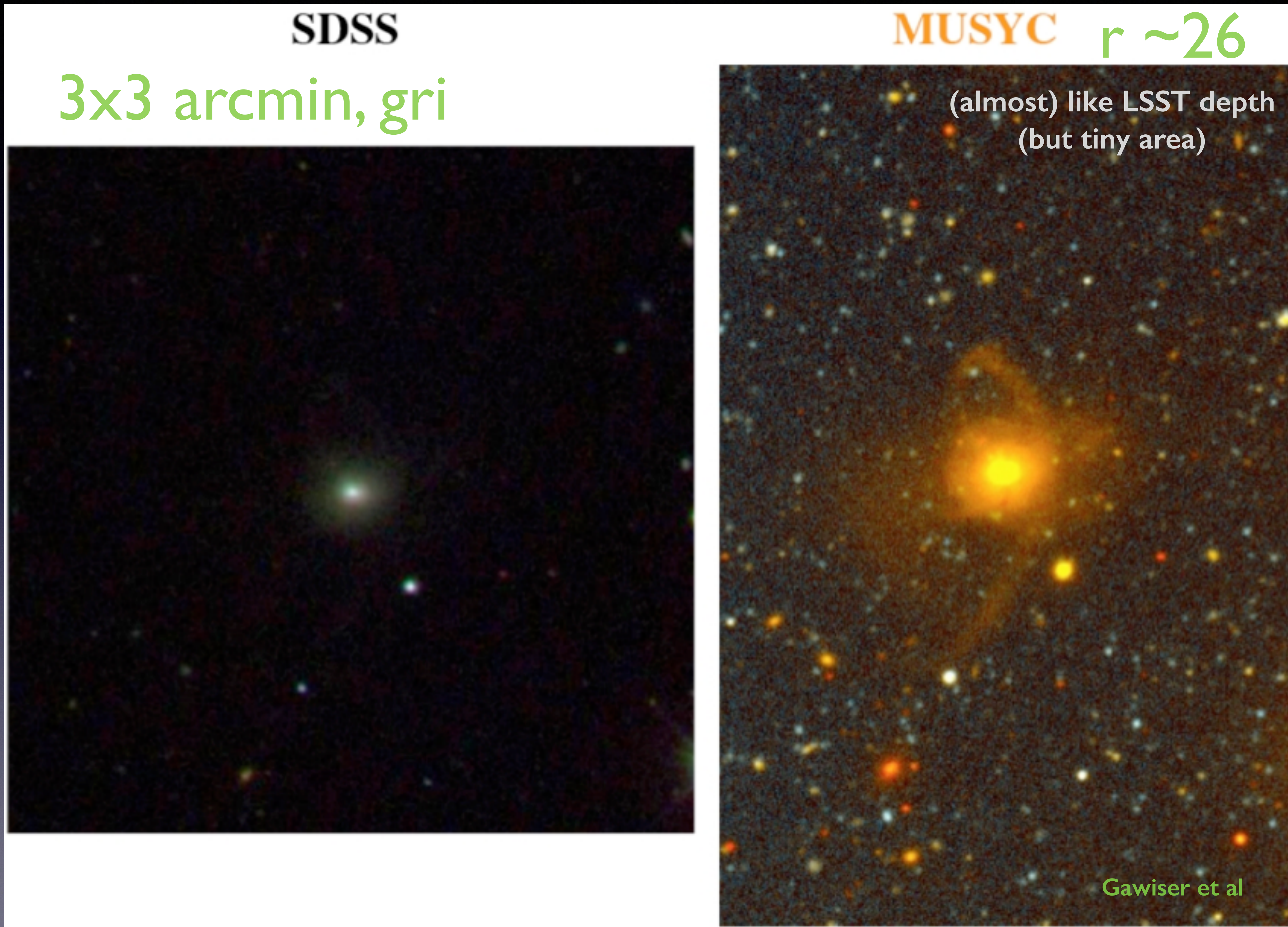


Shoemaker-Levy 9 (1994)

Tunguska (1908)

The Barringer Crater, Arizona: a 40m object 50,000 yr. ago

Extragalactic astronomy: faint surface brightness limit



LSST software

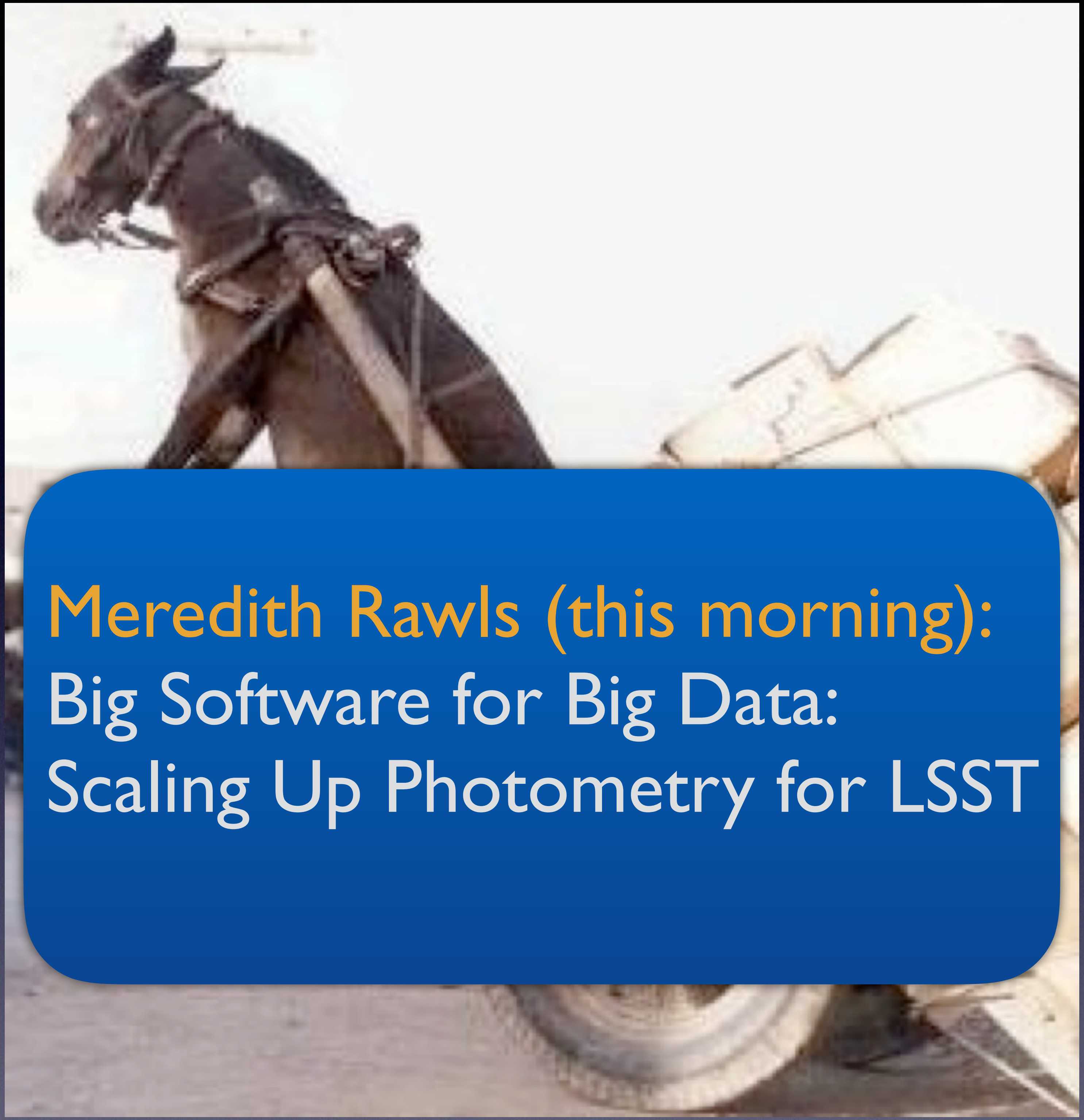
20 TB of data to process every day (~one SDSS/day)

1000 measurements for 40 billion objects during 10 years

Existing tools and methods (e.g. SDSS) do not scale up to LSST data volume and rate (100 PB!)

About 5-10 million lines of code (C++/python)

LSST software



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Scaling Up Photometry for LSST

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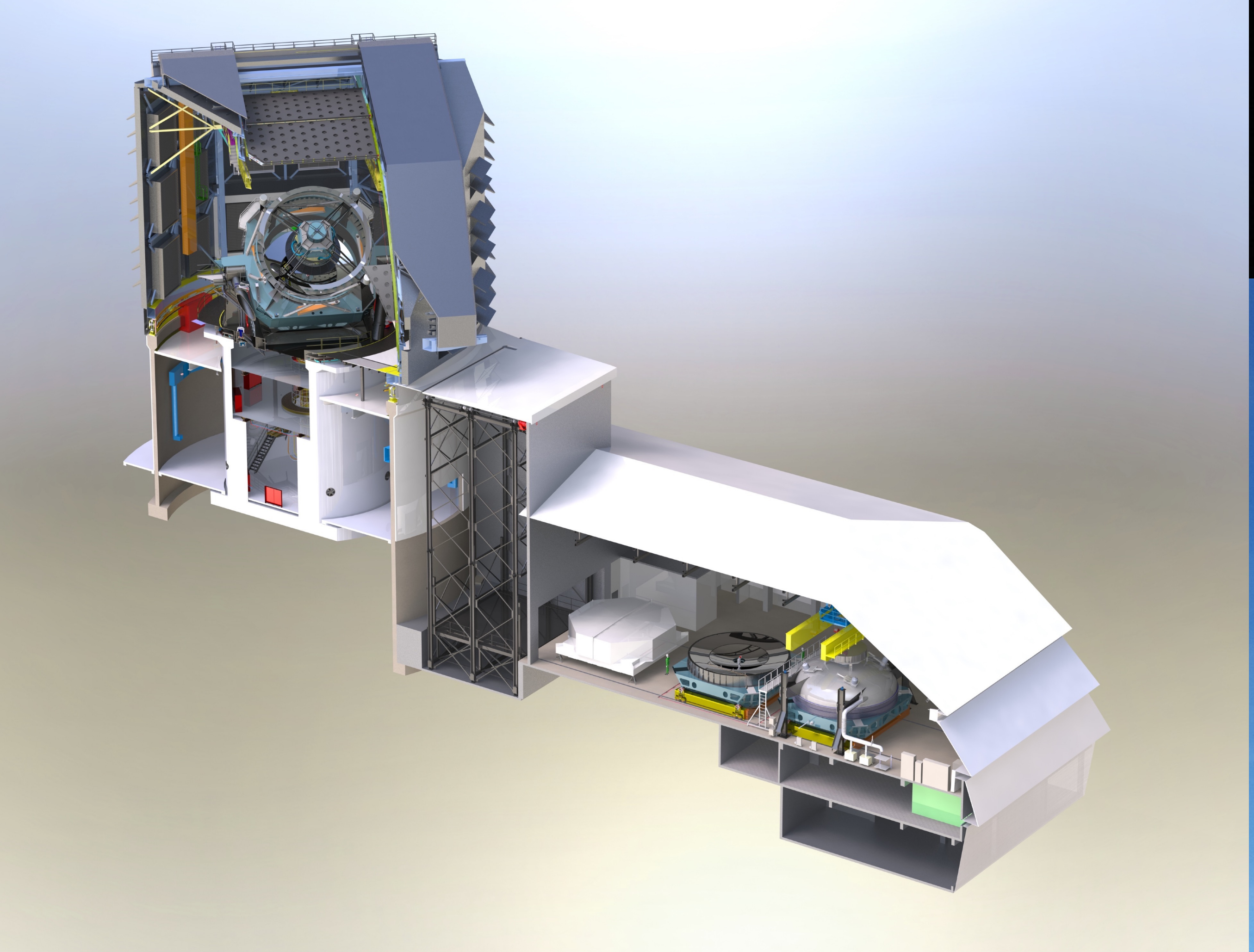
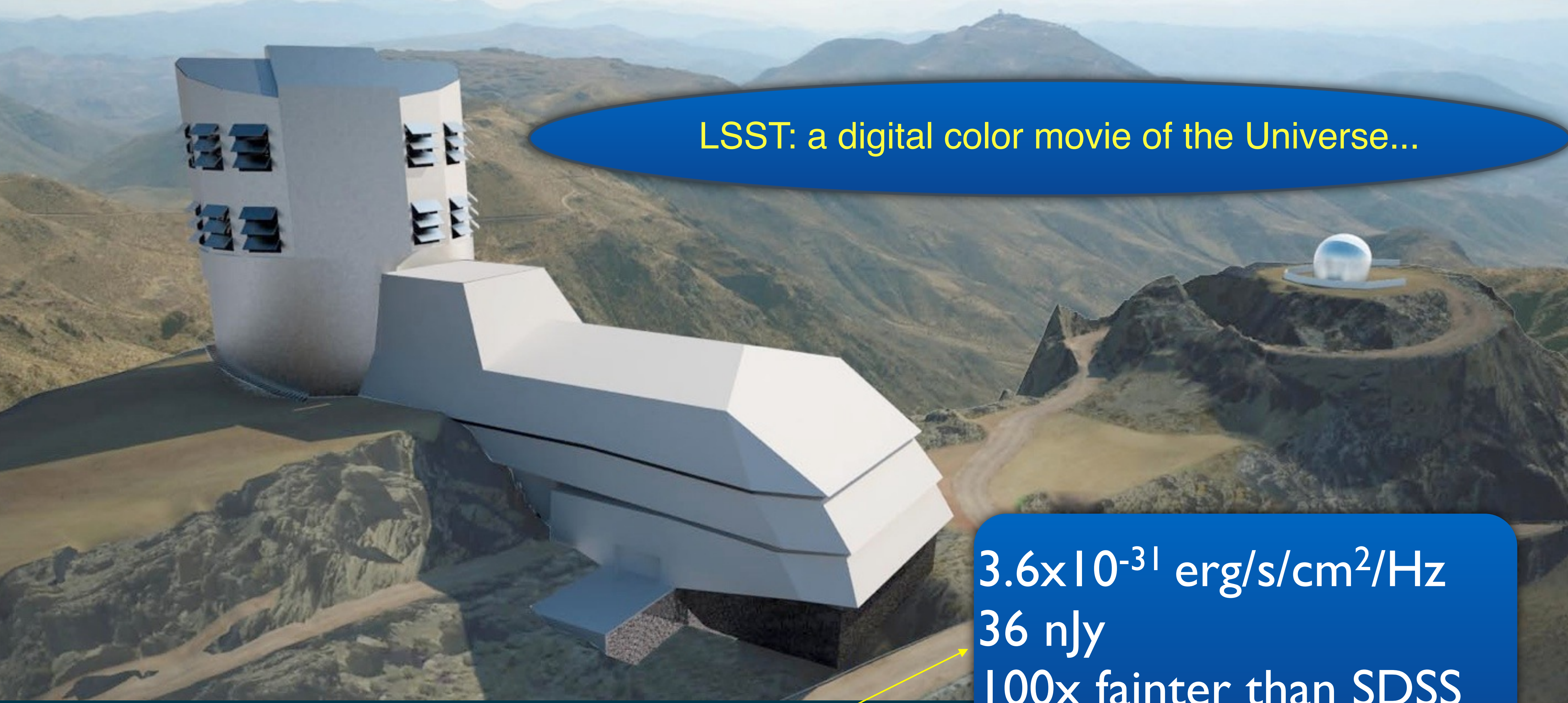
First light: 2019





LSST: a digital color movie of the Universe...

3.6×10^{-31} erg/s/cm^2/Hz
36 nJy
100x fainter than SDSS

LSST in one sentence:

An optical/near-IR survey of half the sky in ugrizy bands to r~27.5 based on ~1000 visits over a 10-year period:

More information at www.lsst.org and arXiv:0805.2366

A catalog of 20 billion stars and 20 billion galaxies with exquisite photometry, astrometry and image quality!

Commentary: The Impact of Large Optical Surveys on Stellar Astronomy and Variable Star Research

The advent of large optical surveys has delivered unprecedentedly large and precise astrometric and photometric datasets (precise magnitudes and colors, well-sampled light curves, sometimes both).

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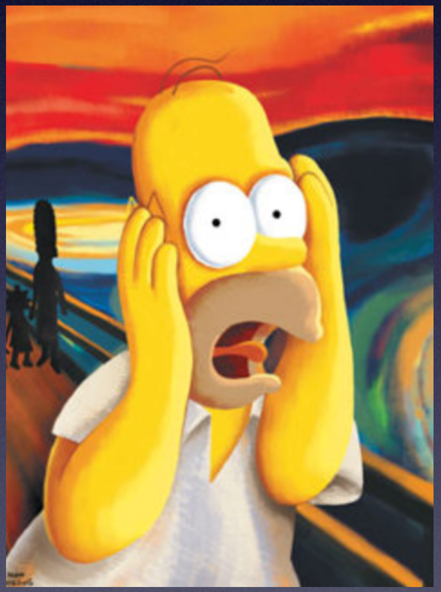

Is this the end of amateur astronomy?
The end of AAVSO? What is left to do?

It seems to me that the role of AAVSO will actually increase because the targets needing attention will be easier to identify and will be more interesting!
I have a good example of such a collaboration…

A Real-life Example: a photometric follow-up of sources selected from the SDSS & LINEAR database with the 1m Austrian-Croatian telescope (ACT) at the Hvar Observatory and a network of private telescopes

Colors + light curves = follow-up

- SDSS provides single-epoch colors
- LINEAR (asteroid survey) provides several hundred observations (to $V \sim 18$) over a few years in a single broad bandpass
- ACT and other telescopes are follow-up instruments for obtaining additional photometry at an arbitrary cadence

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Interesting Sources for a BVRI Follow-up

- RR Lyrae ab: the phase of the light curve minimum is correlated with chemical composition (an interesting quantity for studying the Milky Way history), but need to measure the phase with a precision of ~ 0.01 (a few minutes)
- RR Lyrae c and contact eclipsing binaries: need time-resolved colors to separate them (and enable further science-driven studies)

Single-band light curves for c-type RR Lyrae eclipsing binaries (top panels) are almost indistinguishable (especially when the noise is large), but when the color variation (bottom panels) is available, there is no ambiguity.

Color light-curves are relative easily to obtain (even a few points suffice)

1.

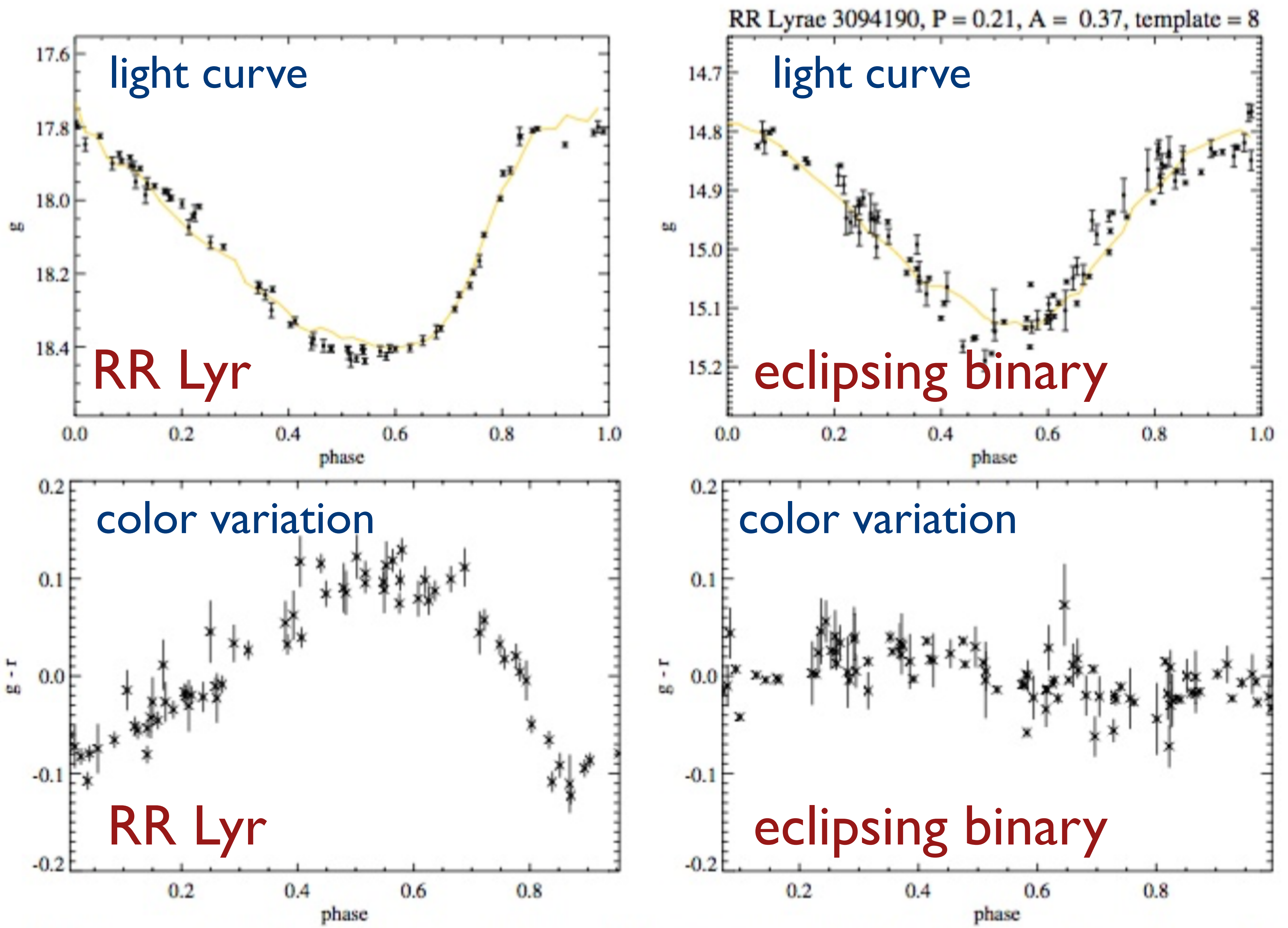

Figure 5. g (top) and $g - r$ (bottom) light curves of an RRc star (left) and a candidate eclipsing binary (right). The best-fit V-band templates are shown as solid lines. Even though their g-band light curves are quite similar, and their periods are in the $0.2 < P < 0.43$ days range typical of RRc stars, their $g - r$ light curves are quite different. The eclipsing binary is outside the Figure 3 (middle) selection box as it has a much smaller rms scatter in the $g - r$ color ($\sigma_{g-r} \sim 0.02$ mag) than the RRc star ($\sigma_{g-r} \sim 0.07$ mag).

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The advent of large optical surveys has provided means to select **extremely interesting** targets where amateur astronomers can provide valuable contributions.

I think that the availabilty of easily accessible survey data, perhaps with access to professional astronomers, gives a boost to AAVSO - **large modern astronomical surveys are your friend!**

I would love to find out if there is any evidence for this assertion!
Please write to: ivezic@astro.washington.edu

Commentary: The Impact of Large Optical Surveys on Stellar Astronomy and Variable Star Research

The advent of large optical surveys has provide means to select extremely interesting targets where amateur astronomers can provide major contributions.

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Thanks again for inviting me!